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Surface Temperature Forecast over Dipayal using Two-way Nesting on Advanced Research and Forecasting (ARW) WRF Modelling System

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Abstract

Extreme temperature results huge loss of life and property. The enhancement of computer aided weather prediction technology has improved the forecast with increasing easiness and accuracy. The study was carried out to analyze the accuracy of the prediction of temperature over Dipayal. In this study, Advanced Research and Forecasting (ARW) WRF model version 4.2 was used. The model down-scaled 0.5° (55 km) Global Forecast System (GFS) data into 30 km x 30 km grid which was further nested twice into 10 km x 10 km and 3.33 km x 3.33 km grid respectively. The nested was done using two way nesting technique.
The model was validated using observed ground station data using simple statistics, quantitative verification (Bias, RMSE and MAE), binary contingency table methods and 1° GDAS FNL data. The study shows that the third domain grid of size 3.3km was 7.42% better than domain 2 and 11.17% better than domain 1. The Bias, RMSE and MAE was -3.03, 3.41 and 3.81 respectively which indicates that the model under predicts the temperature also the forecast is within the range of valid RMSE and MAE. The study indicates that the finer domain was more accurate than the coarser domains and able to simulate temperature more accurately. Moreover, the study shows the Probability of Detection (POD) and False Alarm Rate (FAR) was seen higher in coarser domain than finer domain because of temperature was continuous over larger area.

Keywords

Advanced Research Forecasting (ARW) WRF model – Prediction – Two way nesting – Downscale – Global Forecasting System

1. Introduction

Climate change shows the direct relation with temperature [1]. The enhancement of computer technology has made the simulation easier and faster in forecasting climate variables. In real case scenario, super computers are used for forecasting purpose due to its higher computational capabilities [2].

The Advanced Research WRF were used in various application for more than past twenty years. WRF was able for Weather and Climate prediction using various models [3]. The WRF was able to simulate temperature by two-way nest. In two-way nesting the Finer Grid (FG) and the Coarser Grid (CG) communicate each other during the model run. In other words, the FG inputs the data towards the CG by the method of feedback [4].

The WRF modelling system consists of the major programs:

- Pre-processing
- Processing/Solver
- Post-processing
- Visualisation tools

All of the above process together forms WRF model. The pre-processing decompress the compressed observed data variables and feed to the solver for processing. The solver performs various physics and mathematical operations and present the results for post-processing. The post-processing compress the model results which can be view easily by the visualisation tools. [5].

Himalayan country like Nepal possess complex terrain which makes the parameter required to setup for WRF even more complex [6]. Mixed schemes are required that can solve the increasing complexity from one to many moment.

2. Study Location

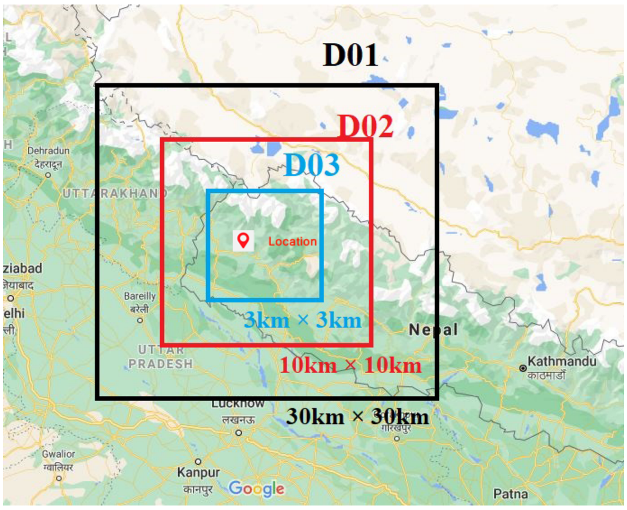

Figure 1: Nested domains for (ARW) WRF

Dipayal lies in the western part of Nepal which is study site. It is located in the Sudurpashchim Province. The point location of the site is 29.26 latitude and 80.94 longitude [7]. The three level down-scaling was done [8]. The location consists of Terai, Hill and Mountains. Because of such terrain change in temperature gives rise to the many climate prone disasters like soil erosion [9], drought etc. which may led to massive destruction of lives and property.

WRF 4.2 was used in this research to predict average temperature. Currently, WRF is being maintained by National Centers for Environmental Prediction (NCEP) [3]. GFS data was taken which was the complex of four models; atmospheric, ocean, land/soil and sea ice having horizontal resolution of 0.5° which was down-scaled in the resolution of 30 km x 30 km was nested successively using two way nesting in the resolution of 10 km and 3.33 km respectively maintaining the ratio of 1: 1/3. And finally validated with the ground observed data provided by the department of hydrology and meteorology, weather forecasting division of Nepal. Figure 1 indicates finer grid and the coarse grid domains.

3. Observed Data

11 days maximum and minimum temperature was taken as observed data further processed to make average temperature using mean over Dipayal station. The observed period was from 24 August 2021 to 3 September 2021 as shown in figure-2. The abscissa axes in terms of no of days while ordinates in terms of temperature in °C .

Table 1: Main characteristics of the Domain 3

No	Characteristics	D03
1	Central Point	Lon:84.2,Lat:28.4
2	Horizontal Step	3.33km
3	Time Step	60
4	Initial and border condition	Domain 2
5	Dimension	94×91×40

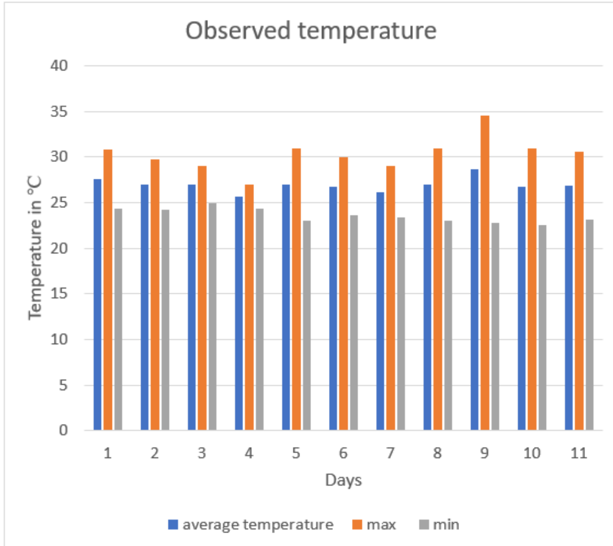

Figure 2: Observational temperature for Dipayal station

4. Model Setup

WRF-4.2 uses the GRIB inventory consisting various meteorological data observed from different centers all over the globe. Static data consists of USGS 24 cateogories as well as MODIS 20 categories for land data-sets [10]. 0.5° GFS data was used for the forecast of temperature [11] with 55km and vertical into 40 layers was setup for the model. The time step for the domains was 60 and the number of meteorological grid levels is 34. Real-data initialization program, compiled with smpar options. The model was run on two way nesting scheme with feedback loop set to 1 . WRF Single-Moment 3 class scheme for micro physics. Rapid Radiative Transfer(RRT) [12] for long wave radiation, Dudhia short wave radiation [13] scheme for short wave radiation which is highly efficient for cloud and clear sky. Noah Land surface model for surface physics and Kain-Fritsnch scheme for cumulus parametrization. 3DTKE for self adaptive grid format [14].

Table 2: Verification using simple mean

No	Variable	°C/ day
1	Mean observed temperature	26.39
2	Mean forecast temperature on D03	23.90
3	Mean forecast temperature on D02	21.90
4	Mean forecast temperature on D01	20.89

5. Verification of Model

Figure 3 shows the forecast data for average temperature in each domain. The model was verified in four ways of verification. One was using mean statistics[15], second was using key performance indicator Bias, RMSE and MAE called quantitative verification [16] the third was using binary contingency table method [17] and the fourth is assimilation using GDAS.

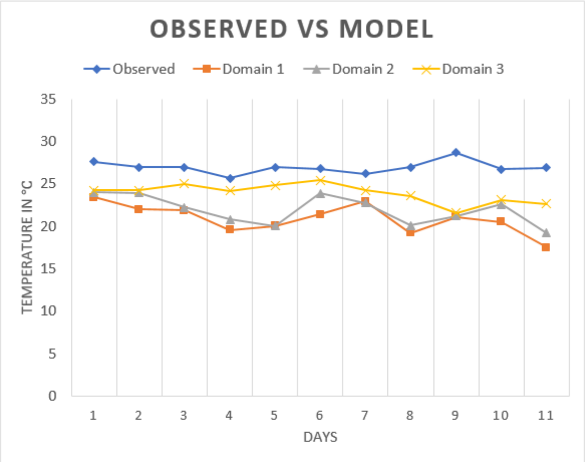

Figure 3: Forecast on temperature for Dipayal station for all three domain

5.1 Verification using simple mean and percentage of forecast

The average temperature per day was calculated for observation with forecast for each domain. Table 2 shows the mean average temperature in all three domain and the mean observed temperature. The average observed temperature was found to be 26.39 °C/ day. Average temperature at domain D01, D02 and D03 is 20.89, 21.90 and 23.90 °C/ day respectively. Considering the domain 3 for verification the accuracy of the forecast was 88.74% which was 7.42% greater than domain 2 and 11.17% better than domain 1 respectively.

Table 3: Verification using quantitative method in all domain grids

Key performance Indicator	D01	D02	D03
Bias (°C/ day)	-6.07	-5.05	-3.03
RMSE (°C/ day)	6.30	5.35	3.41
MAE (°C/ day)	6.02	5.12	3.81

5.2 Verification using key performance indicators of the forecast

Bias, RMSE and MAE is calculated in quantitative method of verification. Bias shows the direction of the forecast, the negative sign indicates that forecast was under predicted while positive sign indicates the forecast was over predicted. The difference in forecast to the observed divided by the number of days gives the Bias. The Bias at different domain was negative as shown in table 3 which indicates the forecast was under-predicted.

Root Mean Square Error is the square root of individual square sum divided by number of days. The RMSE will be high if a single value has the peak error. The table indicates that Root mean square error for forecast was 3.41, 5.35 and 6.30 respectively which was less than 40-60 percent under a valid range [18].

MAE is Mean Absolute Error which gives the absolute error in terms of mean. Note that RMSE is always greater than MAE. The least value of RMSE and MAE is a valid for any forecast of weather variable. The MAE was 3.81, 5.12 and 6.02 for domain 3, 2 and 1 respectively which was in the limit of validity.

5.3 Verification using binary contingency table

Another verification method called contingency table method was used. the threshold of 2 °C was taken into account. The table was made by the logic that hit was assumed if the forecast and the observed values are true and the miss is counted when the forecast cannot be able to predict the the observed. The false alarm is observed when the forecast is true but the observed is false and the correct rejection is observed when the observed is false and so the forecast is. Based on that logic Weighted effective index is calculated that the misses is more significant than that of the false alarm [19]. Table 4 indicates that the POD and false alarm was higher in domain 1. The weighted effective index was greater than the 50% which verify the forecast model.

Table 4: Verification using Binary contingency table

Statistics	D01	D02	D03
POD%	88.60	86.20	84.80
FAR%	28	24	22
WEI%	62.80	65.22	68.88

5.4 Verification using 1° FNL GDAS observed data

1° (111 km) final analysis observed data is obtained for the verification using assimilation technique. The bias of the model forecast and assimilated forecast was done with a value found to be 11..6, 9.88 and 8.25 °C per day which was relatively higher compared to others verification tools. The GrADS showing simulation using GDAS was shown in figure 4.

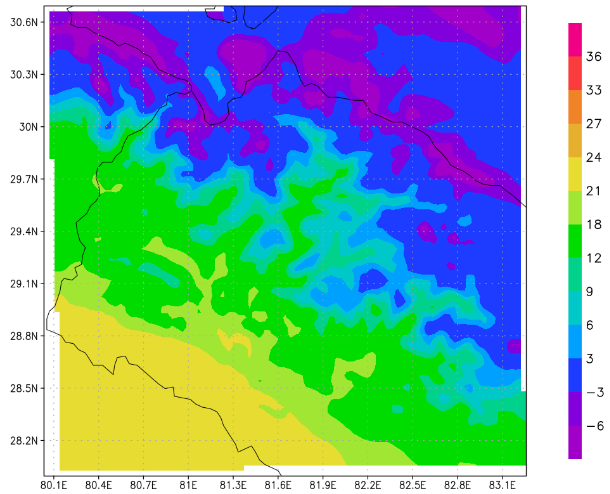

Figure 4: Simulation of temperature using GDAS assimilation

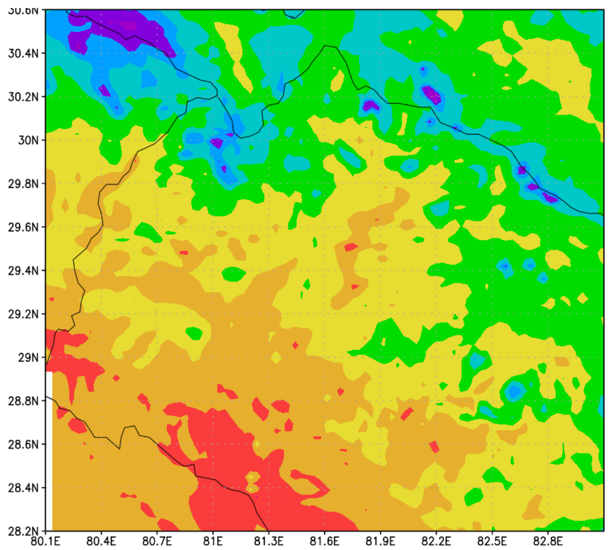

Figure 5: Simulation of temperature in WRF model

6. Results and Discussion

In this research three level of down-scaling was done. The primary domain was D01 followed by D02 and D03 into 30 km to 10 km to 3.33 km of horizontal resolution. Outcome after the model run was analysed using the four verification method. The first verification using simple statistics, the second verification using forecast key performance indicator, the third verification using binary contingency table and the fourth verification using 111 km resolution GDAS observed data. The performance comparison was made among the domains. Table 1 represents the domains description used for the domain 3 of the model.

Table 2 represent that the forecast was in the valid rage of about 85% of accuracy which was considered as the valid one. In table 3 Bias, RMSE and MAE of the domains were shown. Bias was negative indicates that the prediction of the temperature was under shot while RMSE and MAE for the forecast was in the valid range less than 5 °C/ day. The binary contingency verification illustrates that the weighted effective index was greater than the 60% which was valid for all domains. The domain thus modeled was capable to forecast the average temperature of the Dipayal. Figure 5 shows the average temperature through out the study period of time visualized in GrADS.

7. Conclusion

GFS 0.5° degree Global Forecast System data was able to simulate prediction of temperature initialized at 000UTC. The four verification methods are used which clearly indicates that the third nested domain D03 was able to simulate the temperature into higher accuracy than the other coarser domains. The applied micro physics, dynamics and the land surface model was valid for the forecast over Dipayal. The study further concludes that the accuracy of forecast was greater than 80% which shows the model was correct and suitable for the location of Nepal of such terrain and altitudes. On the other hand, the Probability of detection (POD) and False Alarm Ratios (FAR) was higher in the coarser grid than the finer Grid, this is because the coarser grid are more continuous than the finer grid covering more area. However, Weighted Effective Index was greater in the domain 3 which tells that the third domain was accurate to model the output of the forecast.

References

[1] Scott R Loarie, Philip B Duffy, Healy Hamilton, Gregory P Asner, Christopher B Field, and David D Ackerly. The velocity of climate change. *Nature*, 462(7276):1052–1055, 2009.

[2] Dong-Joon Lim, Timothy R Anderson, and Tom Shott. Technological forecasting of supercomputer development: The march to exascale computing. *Omega*, 51:128–135, 2015.

[3] William C Skamarock, Joseph B Klemp, Jimy Dudhia, David O Gill, Zhiquan Liu, Judith Berner, Wei Wang, Jordan G Powers, Michael G Duda, Dale M Barker, et al. A description of the advanced research wrf model version 4. *National Center for Atmospheric Research: Boulder, CO, USA*, page 145, 2019.

[4] Jianhua Qi, Changsheng Chen, and Robert C Beardsley. Fvcom one-way and two-way nesting using esmf: Development and validation. *Ocean Modelling*, 124:94–110, 2018.

[5] Jimy Dudhia. Wrf modeling system overview. *WRF-ARW tutorials. Mesoscale and Microscale Meteorology Division. NCAR. Recuperado de http://www2. mmm. ucar. edu/wrf/users/supports/tutorial. html*, 2014.

[6] Rudra K Shrestha, Paul J Connolly, and Martin W Gallagher. Sensitivity of wrf cloud microphysics to simulations of a convective storm over the nepal himalayas. *The open atmospheric science journal*, 11(1), 2017.

[7] B Upreti and Anil Shakya. Wind energy potential assessment in nepal. *Kanagawa: Japan: The School of Architecture and Wind Engineering, Tokyo â*, 2009.

[8] P Quintana Seguí, Aurélien Ribes, Eric Martin, Florence Habets, and Julien Boé. Comparison of three downscaling methods in simulating the impact of climate change on the hydrology of mediterranean basins. *Journal of hydrology*, 383(1-2):111–124, 2010.

[9] Gobinda Ojha and Raju Shrestha. Bioengineering measures for stabilising cut slopes of dipayal-mallekh road, far western nepal. *Bulletin of the Department of Geology*, 10:79–88, 2007.

[10] Dong Liang, Yan Zuo, Linsheng Huang, Jinling Zhao, Ling Teng, and Fan Yang. Evaluation of the consistency of modis land cover product (mcd12q1) based on chinese 30 m globeland30 datasets: A case study in anhui province, china. *ISPRS International Journal of Geo-Information*, 4(4):2519–2541, 2015.

[11] Chong-Chi Tong, Youngsun Jung, Ming Xue, and Chengsi Liu. Direct assimilation of radar data with ensemble kalman filter and hybrid ensemble-variational method in the national weather service operational data assimilation system gsi for the stand-alone regional fv3 model at a convection-allowing resolution. *Geophysical Research Letters*, 47(19):e2020GL090179, 2020.

[12] Sami Niemelä, Petri Räisänen, and Hannu Savijärvi. Comparison of surface radiative flux parameterizations: Part i: Longwave radiation. *Atmospheric research*, 58(1):1–18, 2001.

[13] Hyeyum Hailey Shin, Song-You Hong, Jimy Dudhia, and Young-Joon Kim. Orography-induced gravity wave drag parameterization in the global wrf: Implementation and sensitivity to shortwave radiation schemes. *Advances in Meteorology*, 2010, 2010.

[14] Song-You Hong and Hua-Lu Pan. Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Monthly Weather Review*, 124(10):2322 – 2339, 1996.

[15] Dhritikesh Chakrabarty. Derivation of some formulations of average from one technique of construction of mean. *American Journal of Mathematical and Computational Sciences*, 3(3):62–68, 2018.

[16] Weijie Wang and Yanmin Lu. Analysis of the mean absolute error (mae) and the root mean square error (rmse) in assessing rounding model. In *IOP conference series: materials science and engineering*, volume 324, page 012049. IOP Publishing, 2018.

[17] Frank Emmert-Streib, Salisou Moutari, and Matthias Dehmer. A comprehensive survey of error measures for evaluating binary decision making in data science. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, 9(5):e1303, 2019.

[18] Elke Lorenz, Jan Remund, Stefan C Müller, Wolfgang Traunmüller, Gerald Steinmaurer, David Pozo, José Antonio Ruiz-Arias, V Lara Fanego, Lourdes Ramirez, Martin Gaston Romeo, et al. Benchmarking of different approaches to forecast solar irradiance. In *24th European photovoltaic solar energy conference*, pages 21–25. Hamburg Germany, 2009.

[19] Aldo S Moya-Álvarez, Daniel Martínez-Castro, Shailendra Kumar, René Estevan, and Yamina Silva. Response of the wrf model to different resolutions in the rainfall forecast over the complex peruvian orography. *Theoretical and Applied Climatology*, 137(3):2993–3007, 2019.